

Chapter 4. Geology and Geotechnical Studies

Regional Geology

The four proposed projects are in the western foothills along the edge of the Sacramento Valley. The rocks underlying the dam sites are part of the Great Valley geomorphic province and are comprised of mostly sandstone, mudstone, and conglomerate. The Great Valley geomorphic province is bounded to the west by the Coast Ranges province, to the north by the Klamath Mountains province, to the northeast by the Cascade Range province, and to the east by the Sierra Nevada province.

Along the west side of the Sacramento Valley, rocks of the Great Valley province include Upper Jurassic to Cretaceous marine sedimentary rocks of the Great Valley Sequence, fluvial deposits of the Tertiary Tehama Formation, Quaternary Red Bluff Formation, Quaternary terrace deposits, Recent alluvium, and colluvium.

Rocks of the Great Valley Sequence form a series of northwest-trending, east-dipping ridges of sandstone and conglomerate separated by valleys underlain by siltstone and mudstone. Notches in the sandstone and conglomerate ridges, called water gaps, were formed by seasonal creeks. The dam sites for all four proposed projects would be founded on the ridges at these water gaps.

Fresh mudstones of the GVS are typically dark gray to black, but weathered mudstones are mostly light brown. In general, the mudstones are thinly laminated and have closely spaced and pervasive joints. When fresh, the mudstones are hard and moderately strong. Exposed units are fragile, weak, and weather and slake readily. Mudstones generally underlay the valleys because of the rocks' susceptibility to weathering and erosion.

Fresh sandstones are light green to gray; weathered sandstones are tan to brown. Sandstone beds range from thinly laminated to massive. The sandstones are often interlayered with beds of conglomerates, siltstones, and mudstones. Massive sandstones are indurated, strong and hard, with widely-spaced joints, and form the backbone of most of the ridges.

The conglomerates are closely associated with the massive sandstones and consist of lenticular and discontinuous beds varying in thickness from a few feet to more than 100 feet. Conglomerate clasts range in size from pebbles to boulders and are composed primarily of chert, volcanic rocks, granitic rocks, and sandstones set in a matrix of cemented sand and clay. The conglomerates are similar to the sandstones in hardness and jointing.

Tertiary and Quaternary fluvial sedimentary deposits unconformably overlie the GVS. The Pliocene Tehama Formation is the oldest. It is derived from erosion of the Coast Ranges and Klamath Mountains and consists of pale green to tan, semi-consolidated silt, clay, sand, and gravel. The Nomlaki tuff member occurs near the bottom of the Tehama Formation and has been age-dated at about 3.3 million years. The Nomlaki is a slightly pink to gray pumice deposit forming a single massive bed about 30 feet thick. Along the western

margin of the valley, the Tehama Formation is generally thin, discontinuous, and deeply weathered.

The Quaternary Red Bluff Formation consists of reddish, poorly sorted gravel with thin interbeds of reddish clay. The Red Bluff Formation is a broad relatively flat deposit that covered much of the Tehama Formation between 0.45 and 1.0 million years ago. Thickness varies up to about 30 feet. The surface of the Red Bluff Formation is an excellent datum to assess Pleistocene deformation because of its original widespread occurrence and low relief. Red Bluff Formation outcrops occur just northeast of the dam sites.

Terrace deposits form flat benches adjacent to and above the active stream channels. Nine different stream terrace levels have been identified. Terrace deposits consist of several to 10 feet of clay, silt, and sand overlying a basal layer of coarser alluvium containing sand, gravel, cobbles, and boulders. Four terrace levels have been given formational names by the U.S. Geological Survey (Helley and Harwood 1985): the Upper Modesto, Lower Modesto, Upper Riverbank, and Lower Riverbank. These levels range in age from 10,000 to several hundred thousand years old. Terrace deposits may be suitable for the impervious core and random fill for the embankment of the proposed dams.

Terrace deposits are also valuable for evaluating the age and activity of faults that trend across them. A number of investigators have applied different types of age dating techniques, together with geomorphic analysis, to date and correlate terrace deposits. Lack of evidence of faulting across the terrace deposits constrains the time of last movement.

Recent alluvium is a loose sedimentary deposit of clay, silt, sand, gravel, and boulders. These include both stream channel and floodplain deposits. Stream channel deposits generally consist of sand and gravel and may be useful as construction material for concrete aggregate, filters, and drains. Floodplain deposits are finer grained and consist of clay and silt. Floodplain deposits may be used for the impervious core of a dam and for random fill.

Colluvium, or slope wash, occurs at the face and base of a hill and consists mostly of soil and rock. Landslide deposits are similar, but are more defined and generally deeper. Landslides often occur along a reservoir rim, but are generally small, shallow debris slides or debris flows. Landslide deposits may be incorporated as random fill in dam construction.

Faulting and Seismicity

Recent work by numerous researchers indicates that an active tectonic boundary between the Sierra Nevadan basement and the Coast Ranges lies buried beneath the entire western edge of the Great Central Valley from Bakersfield to Red Bluff. This system of faults is generally referred to as the Great Valley thrust fault system or the Great Valley fault. The boundary is not a line but a complex geologic region, and the exact location of this fault in the study area is not known.

Activity along this complex zone is characterized by a number of types of faulting, and is considered to be the source of the two 1892 Winters-Vacaville earthquakes (Magnitude 6-7), the 1983 Coalinga earthquake (Magnitude 6.7), and the 1985 Kettleman Hills events (Magnitude 5.5 or 6.1). Many small to moderate earthquakes have also occurred along the full length of the boundary.

These include a Magnitude 5.8 in 1866, a Magnitude 5.9 in 1881 west of Modesto, and a Magnitude 6.0 in 1889 near Antioch. The deeper faulting manifests itself on the surface as low hills on the west side of the valley like those near Corning and the Dunnigan Hills.

Since no definitive surface faulting exists, the analysis of microseismic data becomes an important tool to define the extent of the fault and its seismic potential. Wong et al. (1988) believes that a Magnitude 7 earthquake could possibly occur anywhere along the boundary.

The Working Group on Northern California Earthquake Potential and other workers have divided the Great Valley fault into a number of segments that act independently of each other. The segments of interest to this study are designated by the working group as GV01, with the source near the Salt Lake fault and Sites anticline, and GV02 outside the project area to the south, centered on the Cortina thrust. GV01 has been assigned a magnitude of 6.7 with a recurrence interval of 8,300 years and a slip rate of 0.1 mm per year (USGS 1996).

In the Phase I Fault and Seismic Hazards Investigation (Appendix O), DWR concluded that the design earthquake was a maximum credible earthquake of Magnitude 7.0 occurring directly under the Sites, Golden Gate, Hunters, Logan, or Newville Dam sites at a depth of about 6 miles on the Great Valley fault. This earthquake would have a duration of about 26 seconds, a peak horizontal acceleration of 0.7 gravity, and a predominant period of 0.32 seconds. This is assumed to be a conservative estimate. DWR's fault and seismic consultant, William Lettis and Associates, also considers this conservative, with a Magnitude 6.5 to 6.75 more likely.

Earth Sciences Associates (1980) concluded that all the faults near the Thomes-Newville Project's principal engineering structures are pre-Quaternary in age (over 1 million years old) and surface offsets need not be considered in project feasibility studies. DWR will revisit this conclusion during the Phase II Fault and Seismic Investigation.

The Salt Lake fault and the associated Sites anticline and adjacent Fruto syncline extend from near Sites about 40 miles north to near Newville. The anticline is a tight fold with steeply dipping and locally overturned strata on both limbs. Based on analysis of seismic reflection data, William Lettis and Associates (1997) interprets the anticline as a fault-propagation fold developed above one or more blind thrust faults. The faults are truncated by a sub-horizontal detachment at a depth of about 3 miles.

The Salt Lake fault is a high-angle thrust fault that developed adjacent to the axis of the doubly plunging Sites anticline (DWR 1978). Salt water springs and gas seeps along the fault trace are suggestive of recent fault activity. In several locations, however, the fault is concealed by unbroken Pliocene Tehama Formation suggesting that the latest movement occurred over one million years ago.

Based on the work done by the consultant and the Working Group on earthquake potential, it is probable that the Salt Lake fault, the Sites anticline, and the Fruto syncline are features related to the Great Valley fault. The fault trends within 1 mile of most of the Thomes-Newville and Colusa project dam sites, and possibly crosses the upstream edge of the Sites dam site. The Sites anticline (Kirby 1943) and the Fruto syncline (Chuber 1961) are flexures

extending in the northwest direction from the general area of Sites possibly as far north as Newville. Table 4-1 shows the preliminary seismic design parameters, except for the Gorda plate at Newville, which has not yet been evaluated.

**Table 4-1. Draft Preliminary Seismic Design Parameters
for the Proposed Projects**

Project	Maximum Credible Earthquake Magnitude	Distance (km)	Depth (km)	Peak Acceleration (g)	Duration (seconds)	Period (seconds)
Sites and Colusa	7.0	0	10	0.70	26	0.32
Thomes-Newville	7.0	0	10	0.70	26	0.32
Red Bank	8.3	0	35	0.72	28.5	0.42

Note: Preliminary design parameters subject to change as new information becomes available.

William Lettis and Associates is currently working on the Phase II investigation, which includes trenching and detailed seismic analysis of the dam sites. Their results are preliminary and incomplete at this time. They have found that the faults are typically expressed within bedrock as well-defined, narrow (2 to 5 feet wide) zones of moderately to highly fractured rock with less than 1 to 2 feet of fault gouge.

The Quaternary stream, terrace, and slope deposits provide preliminary constraints on the activity of these faults. Detailed soil profiles in the trenches suggest that deposits within all trenches are roughly correlative and probably early Holocene to latest Pleistocene in age, or 8,000 to 15,000 years old (WLA 2000). No surface rupturing events have occurred on these faults during this time. Geologists continue to look for deposits that have been disturbed by faulting. This will help determine the actual age of the most recent fault movement.

Sites Project

Both DWR and the U.S. Bureau of Reclamation have conducted geologic studies for Golden Gate and Sites Dam sites. Geologic data gathered to date suggest that the foundations are adequate for the proposed structures. The majority of the construction material is readily available locally, but riprap, filter, transition, and concrete aggregate may have to be imported from distances up to 50 miles.

Golden Gate Dam Site Geotechnical Studies and Findings

Currently, there are three axial alignments for Golden Gate Dam being considered. These are the upstream straight alignment, the downstream curved alignment, and the downstream straight alignment. Only the downstream straight alignment has been investigated as part of this study to date.

Bedrock

The Golden Gate Dam site consists of northwest trending and moderately to steeply northeast dipping interbedded sandstone and mudstone of the Boxer and Cortina formations. The overall composition is about 65 percent sandstone and 35 percent mudstone.

Rock Strength

DWR (Appendix Q) has measured compressive strengths of foundation rocks. Compressive strengths of the sandstone and conglomerate generally range from 9,000 to 12,000 pounds per square inch. The mudstone generally varies from 3,000 to 6,000 psi. However, these samples are not fractured or jointed. Overall strength of the foundation rock will vary depending on the amount of jointing, fracturing, and faulting. For comparison purposes, general purpose concrete has compressive strengths from 3,000 to 5,000 psi.

Surficial Deposits

Quaternary to Recent deposits include colluvium, alluvium, landslide, and terrace. Stream gravel deposits are minor and range in thickness to about 5 feet. Colluvium typically ranges from 5 feet to about 15 feet at the base of slopes. Two minor landslides have been identified, a small recent slide on the right abutment and a larger and older slide deposit on the left abutment. Terrace deposits are the most extensive, mostly Upper Modesto and possibly Lower Riverbank Formations. These average 15 to 20 feet thick, but may reach a thickness in excess of 25 feet. The composition is variable, but generally consists of an upper layer of silt and soil, and a thin lower layer of clayey gravel and cobbles.

Structure

Two faults, GG-1 and GG-2, traverse through the foundations of the proposed axes. Faults GG-1 and GG-2 were mapped by Brown and Rich (1961). GG-2 extends from the right abutment, crosses the channel slightly downstream of the axis, crosses the left abutment, and then extends an additional 2 miles in a northeast direction before it terminates or cannot be traced in the mudstones to the east. Apparent right lateral displacement is estimated to be in the range of 600 to 1,200 feet. Fault GG-1 is shorter and extends across the left abutment of the upstream dam axis, then trends northeast and misses the left abutment of the downstream dam axis. Apparent right lateral displacement is estimated to be about 50 feet.

GG-3, which does not trend through any of the proposed foundations, was also mapped by Brown and Rich (1961). It is parallel to GG-2 but about 4,000 feet further to the south. William Lettis and Associates, the Phase II Fault and Seismic contractor, excavated trenches across all three faults. Their preliminary findings indicate no evidence of faulting within the surficial deposits.

The Salt Lake fault is less than 1 mile to the west. Although the fault is considered potentially active at this time, it does not cross any of the proposed dam foundations. The fault may be one of several expressions of the deep-seated Great Valley fault.

Exploration

USBR drilled and water pressure tested three diamond core drill holes at the upstream straight axial alignment and one hole at the proposed powerhouse location. DWR drilled an additional four diamond core holes and three auger holes near the downstream straight alignment foundation. Three of the core holes were drilled downstream of the axis and the fourth was an angle hole drilled near the channel and oriented to intercept fault GG-2. Seven seismic refraction lines were surveyed at the dam site and outlet structure, totaling 1,000 feet in length. William Lettis and Associates excavated three trenches across fault GG-1, three trenches across GG-2, and two trenches and three test pits across GG-3.

At the proposed Golden Gate inlet and outlet facilities, DWR drilled five holes. Two diamond core holes were drilled along the tunnel alignment; two holes along alternative spillway alignments; and one hole at the pumping plant.

Three shallow (up to 34 feet deep) auger holes were drilled along the proposed canal from Funks Reservoir to the pumping plant. In addition, eight holes were augered to facilitate trench locations for the regional fault investigations.

Permeability and Grouting Requirements

Preliminary analysis of the water pressure test data indicates that grout takes should be mostly low to moderate, with some areas of high take. Abutment holes at the Golden Gate Dam site have permeabilities averaging 0.26 feet per day, with higher values and grouting requirements on the right abutment. Channel hole permeabilities are lower, averaging 0.15 feet per day.

Foundation Preparation, Clearing, and Stripping

Both abutments and the channel are covered by grass with no brush or trees and require no clearing. About 20 feet of alluvium and terrace deposits in the channel should be easily stripped using common methods. Up to 20 feet of moderately weathered bedrock may require some blasting and removal by common methods.

About 5 feet of soil, colluvium, and intensely weathered bedrock on both abutments may be stripped using common methods. Another 5 to 20 feet of moderately weathered bedrock may require blasting for abutment shaping and then material removal.

Construction Materials

More information about construction materials required for Golden Gate Dam can be found in Appendix P. Impervious core material is available from terrace deposits within 1 mile of the dam site, in the reservoir inundation area. Excavation for the spillway, powerhouse, tunnel, and canal will provide much of the required random and rock fill. Additional material is available directly upstream or downstream, depending on which dam alignment is selected. Concrete aggregate, riprap, and filter material sources are the same as for Sites.

Sites Dam Site Geotechnical Studies and Findings

The dam alignments proposed by DWR and USBR for Sites Dam are basically the same. The major design difference is that the DWR embankment crest elevation would be higher.

Bedrock

The Sites Dam foundation consists of northeast-dipping interbedded sandstones and mudstones of the Upper Cretaceous Boxer and Cortina Formations. The Sites Dam site area consists of about 50 percent sandstone and 50 percent mudstone, mostly interlayered, with beds typically ranging from less than 1 inch to tens of feet.

Surficial Deposits

Quaternary to Recent deposits include colluvium, alluvium, terrace deposits, and landslide deposits. Minor alluvium consisting mostly of sand, gravel, and some slabs of sandstone occurs in the stream channel. Terrace deposits are the most abundant, occurring both upstream and downstream of the dam axis. The terrace deposits typically range in depth from 15 to 30 feet and consist mostly of silt, sand, and clay. Colluvium averages about 5 feet on the abutments but may reach depths of 15 feet at the base of slopes. Several small landslides occur on the left abutment and a larger slide occurs on the right abutment. This landslide deposit is probably about 30 feet thick at the base but thinner at the top. It is approximately 200 feet high and 75 feet wide at the base.

Structure

Possible faults at the Sites Dam site include Lineament S-1 and Fault S-2. S-2 was mapped by Brown and Rich (1961) and extends from near the vicinity of the town of Sites. Then it trends northeast through the right abutment, crosses the channel near the downstream toe and extends downstream of the left abutment beyond the footprint of the dam. The fault is about 5 miles long and has a right lateral displacement of about 100 feet. S-2 was trenched fall 1999. The trenches showed no disturbance in the overlying alluvial deposits. The age of the alluvial deposits is presently uncertain, but is believed to be 8,000 to 15,000 years old.

Lineament S-1 was not mapped by Brown and Rich (1961) or by USBR (1969). This lineament, or suspected fault, may trend from the left abutment, then across the channel near the axis, and through the right abutment. Drill hole LC-3 intersected gouge and fractured rock apparently associated with a fault. There is a possibility that the lineament is a southward extension of the Salt Lake fault, which is shown by Brown and Rich (1961) to terminate about 2 miles north of the dam site. This lineament will be considered further in the Phase II field investigation.

Bedding of the bedrock units generally trend northerly and dip 50 to 70 degrees to the east. Joints generally trend parallel and perpendicular to the bedding. Both joint sets are of concern on the abutments because of a tendency for the joints parallel to the creek to be open within the ridge. This condition may require some abutment shaping and more grouting.

Exploration

USBR investigated Sites Dam site in the 1960s and 1980s and drilled three diamond core holes in the foundation. DWR has recently completed mapping, trenching, augering, diamond core drilling, and geophysical surveys. Four holes totaling 740 feet were drilled during the summer of 1998. Two holes, LC-1 and LC-3, were diamond core drilled in the channel downstream of the dam footprint to intercept Fault S-2. Two additional holes, LC-2 and LC-4, were drilled to intercept Lineament S-1. Two of the four holes were water pressure tested. Three auger holes, totaling 41 feet, were drilled to estimate overburden and depth to bedrock. William Lettis and Associates excavated three trenches across Fault S-2, several miles northeast of the dam site.

Permeability and Grouting Requirements

Preliminary analysis of water pressure test data indicates that grout takes should be mostly low to moderate, with some high. The average permeability of the four channel holes is a relatively low 0.15 feet per day. USBR drilled the abutments in 1979 and 1980. Review of this data shows that the left abutment has an average permeability of 0.54 feet per day. The right abutment has a higher average permeability of 1.29 feet per day, possibly due to the S-2 fault crossing the right abutment.

Foundation Preparation

The channel section has a sparsely vegetated riparian zone with scattered fig trees, willows, cottonwoods, and other trees. Vegetation is mostly grass with a few blue oaks on the left abutment. The right abutment is mostly blue oaks and grass. The tree density is higher on the right abutment because of the north-facing slopes and the colluvial and landslide deposits near the base of slopes.

The 15 feet of alluvium and terrace deposits in the channel area can be removed by common methods. An additional 3 to 10 feet of weathered bedrock may need to be blasted and removed. Soil, loose boulders, and weathered bedrock may be removed by common methods on the abutments to depths ranging from 1 to 10 feet. Landslides and colluvium at the base of the slopes probably range in thickness from a few feet up to 30 feet. These deposits must also be removed during foundation excavation. An additional 10 to 15 feet of weathered and fractured bedrock will probably have to be removed by common methods. Some blasting may be required to shape the abutments.

Construction Material

Construction materials for the proposed embankment dam include impervious fill for the core, random or rock fill for the shell with riprap at the surface, filter and drain material, and aggregate for concrete structures. Construction materials for Sites Dam are described in Appendix P.

The sources of the impervious core material are terraces along Antelope and Stone Corral Creeks. The field classification of this material is silty clay to clayey silt with a slight amount of gravel in the stream channel, and appears to be suitable for the impervious fill zone. In spring 1998, terrace samples were collected and analyzed at seven different locations where the terrace is exposed

along Funks and Stone Corral Creeks. Fifteen test pits were excavated into the terrace deposits in the Sites Reservoir area. Generally, three samples were collected from each test pit for laboratory analysis.

One source of rockfill and random fill is the existing Sites quarry in the Venado sandstone downstream of the dam site. Material stripped from the foundation excavation can be used in this zone. Preliminary testing indicates that the crushed quarried rock would probably not be suitable for the filter and drain material because of low durability. During spring 1998, Bryte Laboratory analyzed ten 3-inch cube samples of the quarry rock. During March 1999, approximately 5 cubic yard samples of the weathered and fresh sandstone were crushed and taken to the Bryte Laboratory for further testing. During May 1999, ten rock cores each of the weathered and fresh sandstone from the Sites quarry were collected and analyzed.

A study has been initiated to identify replacement filter and drain material sources. Various sources will be evaluated to determine the most feasible source with the least environmental impacts. Possibilities include the commercial gravel pits near Willows and Orland, and Stony Creek upstream of Black Butte. Construction material investigations are continuing to better define these sources.

Crushed quarried sandstone also may not be suitable for use as concrete aggregate. The commercial gravel pits near Willows and Orland are possible sources for concrete aggregate. Quarried sandstone has been considered marginal for the use as rock riprap on the dam shell. Riprap is available on the east side of the Sacramento Valley near Deer Creek, a distance of about 70 miles.

Sites Reservoir Saddle Dam Sites, Geotechnical Studies and Findings

The proposed DWR Sites Reservoir saddle dam configuration and alignments follow the USBR proposal and consists of nine separate saddle dams (SSD-1 through SSD-9) for a reservoir elevation of 520 feet. The saddle dam sites have been mapped by USBR and DWR.

Bedrock

The Boxer Formation underlies the foundations. It consists mostly of mudstone with some interbedded sandstone and conglomerate. SSD-1 is underlain by mostly mudstone. SSD-2 is underlain by the Salt Lake fault, an 800-foot-wide zone of fractured, folded, and faulted Boxer mudstone with interbedded sandstone. The SSD-3 area is underlain by stream alluvium and colluvium in the channel area, and Boxer on the abutments. SSD-4, -5, -7, -8, and -9 are all underlain by Boxer mudstone with some interbedded sandstone. SSD-6 is underlain by conglomerate. The rock strengths of these units are described under the Sites Dam site description above. It is expected that the rock strength within the Salt Lake fault zone will be less.

Surficial Deposits

Surficial deposits consist of stream channel alluvium and terrace deposits, mostly at SSD-3. Colluvium covers the slopes and collects at the slope base at most of the dam sites.

Structure

The upturned Upper Cretaceous sedimentary rocks consist of north-south trending mudstone, sandstone, and conglomerate. The degree of dip and direction is variable because of deformation along the Salt Lake fault and the Sites anticline.

The Salt Lake fault trends north through the saddle dam alignment at SSD-2. The fault zone is locally about 800 feet wide, mostly consisting of folded and fractured mudstone. Numerous springs, gas seeps, and small mudflows mark the trace of the fault.

The Sites anticline trends normal to the saddle dams roughly parallel to and directly west of the Salt Lake fault. The anticline trends north from the town of Sites along Antelope Valley for about 24 miles. The folding is believed to be a result of movement on buried blind thrusts related to the Great Valley fault. The Fruto syncline is near the western part of the saddle dam alignment, where the beds dip at a shallow angle to the west and to the east.

Exploration

Only preliminary geologic mapping has been completed at the saddle dam sites. Additional evaluation, including subsurface geological exploration, is needed to investigate overall formation permeabilities. USBR drilled and water pressure-tested 13 diamond core drill holes along the saddle dam alignments, generally in the wind gap portions of the saddle dams. In 1999, DWR's Northern District drilled two angle holes at SSD-3 and one vertical hole at SSD-6.

Permeability

DWR has not conducted any water pressure testing to date. USBR conducted water pressure testing in most of their 13 shallow drill holes. The data shows that permeability is generally low to moderate.

Foundation Preparation

The saddle dam areas are covered by closely cropped non-native grasses and only minor clearing is required. Rough estimates range from several feet up to 25 feet of colluvial overburden in the channel that needs to be stripped and removed. An average stripping estimate for the saddle dam sites includes 11 feet of overburden and several feet of weathered bedrock. Grouting requirements have not been developed, but a preliminary review of USBR permeability data indicates that the amount of grouting needed will be minor.

Construction Materials

The saddle dams will be embankment-type structures, either earthfill or rockfill. The same sources as for Golden Gate Dam are available. Terrace deposits for the impervious core can be found within several miles of each of the saddle dams. The random fill or rockfill parts of the embankment may include material stripped from the foundation, quarried sandstone, and terrace deposits. The source of the rockfill would be the sandstone ridge north of Golden Gate Dam site.

Colusa Project

Sites Reservoir geology and geotechnical analyses are applicable for the Colusa Project, with the exception of the discussion related to the saddle dams. These are the only structures that will not be part of both projects. The following section will focus on the geology and geotechnical analyses related to the Colusa Cell.

Limited geologic data have been gathered at the Hunters and Logan Dam sites. At the present reconnaissance-level of study, the foundations appear suitable for the proposed structures. The Colusa saddle dams have not been investigated. No studies of fault activity have been conducted. Sources of impervious core construction materials are available in the reservoir area. Sources of filter, transition, rockfill, concrete aggregate, and riprap material have not been identified.

Hunters Dam Site Geotechnical Studies and Findings

The Hunters Dam site consists of a single dominant ridge along the entire alignment and is made up of four dam sections including the saddle CSD-2, Prohibition, Owens, and Hunters. The total crest length of the proposed dam exceeds 14,000 feet. The dam would mantle the ridge and cross three water gaps formed by the North, Middle, and South Forks of Hunters Creek.

Bedrock

Hunters Dam site foundation consists of northwest trending and moderately to steeply northeast dipping interbedded sandstones and mudstones of the Upper Cretaceous Boxer and Cortina Formations. In general, the bedrock units consist of 40 percent sandstone with 60 percent interbedded mudstone and some minor conglomerate.

Laboratory results from the drill holes at Middle Fork Hunters Creek water gap show a variation in rock compressive strength from less than 1,000 to over 17,000 psi. The results are shown in Appendix Q.

Surficial Deposits

Only limited preliminary mapping has been done at this dam site. Alluvial deposits occur in all three water gaps, consisting of stream channel deposits and terrace deposits. Alluvial deposits are less extensive than at Golden Gate Dam site. Several shallow mudflows and debris slides occur in the water gaps and along the ridge.

Structure

The sandstone, mudstone, and conglomerate strike approximately north-south and dip 55 to 75 degrees east. The Salt Lake fault and the Sites anticline, described previously, are less than 1 mile to the west.

Two northeast trending vertical faults cross the ridge, one just north of the south fork and one about a quarter mile north of the north fork. Estimated offsets are 75 to 100 feet; recent movement is not apparent. As the studies progress, these faults will be evaluated in more detail.

Water pressure data indicate mostly low to moderate grout takes with some high takes. This is caused by open joints both parallel and perpendicular to the bedding.

Exploration

Reconnaissance mapping at the dam site has been completed. Four diamond core holes were drilled and water pressure tested in the middle fork water gap. No subsurface exploration has occurred at the south or north fork water gaps.

Permeability

The abutment holes on the middle fork have higher permeabilities than the abutments at Golden Gate, averaging 0.63 feet per day. Weathering, jointing, and fracturing account for the higher permeabilities and associated high water takes during the drilling.

Foundation Preparation

The dam site is covered by closely cropped non-native grasses. A limited number of trees (2 to 10) grow in each water gap. Clearing requirements are minimal.

Rough estimates of stripping range from 5 to 10 feet of colluvial overburden on the abutments, and 10 to 20 feet of alluvium and terrace deposits in the channel. It is estimated that grouting requirements will be low in the channel areas, but moderate to high on the ridges and abutments.

Construction Materials

The geologic investigation of construction materials is described in Appendix P. Terrace deposits were mapped in the Hunters, Logan, and Minton Creeks and other unnamed drainages. The mapped area of the valley floors occupied by the deposit is 960 acres with an estimated volume of 15,550,000 cubic yards. The terrace deposits along the drainages in the Colusa Reservoir area are not as extensive as along Funks and Antelope Creeks. The field classification of the terrace material exposed in the incised stream channels is silty clay to clayey silt with some gravel.

The volume of impervious fill required for the Hunters and Logan Dams and the Colusa saddle dams is 13,200,000 cubic yards, or about 8,200 acre-feet. Some quality material may have to be imported from the Sites Reservoir area. Haul distances of 3 or more miles would be required to transport this material to the dam sites. Nearly all of the terrace deposits inside the reservoir footprint would be utilized. The deposits of intensely weathered Boxer Formation mudstones that occur in the area are another potential source of impervious fill material. Some of these deposits have been observed with thicknesses of 12 or more feet. As studies proceed, laboratory analyses of these deposits will be required.

A source for the random or rockfill material has not yet been identified. The required volume is approximately 60,000,000 cubic yards. This volume of Venado sandstone is not available within the reservoir footprint. The ridges of

Venado sandstone upon which the Hunters and Logan Dams are based are single ridges, not double ridges like the Golden Gate and Sites Dam sites. Using the analogy of a ridge quarry of 300 by 300 feet, a ridge over 3 miles long would be required to supply the required volume of material. Some of the rockfill may have to be brought in from the Golden Gate quarry and some may be available from spillway excavation.

Transition, drain, filter, and rock riprap construction material sources have not been identified but probably would be the same as for Sites and Golden Gate dam sites.

Logan Dam Site Geotechnical Studies and Findings

The dam site consists of a single dominant ridge along the entire alignment. The total length of the dam axis would be about 7,200 feet.

Bedrock

In general, the bedrock consists of tilted Upper Cretaceous sedimentary rocks made up of 45 percent sandstone and 55 percent interbedded silty mudstone with some conglomerate. The beds trend north-northwest and dip about 60 degrees to the east. The foundation consists of about 45 percent sandstone and 55 percent mudstone.

Surficial Deposits

Surficial deposits of stream channel alluvium and terrace deposits occur in the channel area. Landslide deposits and colluvium occur along the bases and sides of the ridge.

Structure

The conglomerate, sandstone, and mudstone strike north-south, and dip from 55 to 75 degrees to the east. Two tentative northeast-trending, vertical faults occur across the left abutment with estimated offsets of 50 to 75 feet; the occurrence or amount of recent movement has not been determined. The Logan Creek water gap does not exhibit evidence of faulting.

Exploration

Preliminary mapping has been completed at Logan Dam site, but no subsurface investigations have been performed.

Foundation Preparation

Closely cropped non-native grasses cover the dam site. A limited number of trees (less than 30) grow in the Logan Creek water gap. Clearing requirements are minimal. Rough stripping estimates range from 5 to 20 feet of colluvial overburden on the abutments, and up to 20 feet of alluvium and terrace deposits in the channel.

No drilling or water pressure testing has been done. Drilling at dam sites to the south suggests that similar values are likely at Logan Dam site and that the channel area will have low grouting requirements. The abutments may have

moderate to high requirements. This is because open joints may be present on the ridges and abutments.

Construction Material

Construction materials available for Logan Dam site are the same as for Hunters Dam site.

Thomes-Newville Project

DWR and USBR have conducted geologic studies for the Thomes-Newville Project. Geologic data gathered to date suggest that the foundations are adequate for the proposed structures. The majority of the construction material is readily available locally, but riprap, filter, transition, and concrete aggregate may have to be imported from distances up to 50 miles.

Newville Dam Site Geotechnical Studies and Findings

USBR's "Paskenta-Newville Unit, Engineering Geology for Feasibility Estimates, Lower Trinity River Diversion, North Coast Project, California," was the first major work done at Newville Dam site. This was followed by DWR's work from 1978-1982. Most of DWR's work is documented in three reports:

1. "Thomes-Newville and Glenn Reservoir Plans Engineering Feasibility Report," November 1980
2. "Engineering Geology of the Newville Dam and Burrows Gap Saddle Dam Sites, Glenn County, California," December 1982
3. "Thomes-Newville Unit – The 1980-1982 Construction Materials Investigations," December 1982

Bedrock

Newville Dam would be founded on sandstone, mudstone, and conglomerate of the Jurassic to Cretaceous Stony Creek Formation and Cretaceous mudstones of the Lodoga Formation. Both of these formations are part of the Great Valley Sequence.

Rock Strength

The sandstone and conglomerate are massive and strong, but in places have open fractures near the ground surface. The conglomerates and sandstones have unconfined compressive strengths that range from 5,000 to 26,000 psi. The mudstone slakes readily when exposed, and ranges from weak to moderately strong and hard depending on freshness, bedding, and fracturing.

Surficial Deposits

Colluvium, stream channel deposits, and terrace deposits cover about 20 percent of the foundation area. Alluvial depths in the active stream channel average 5 feet and consist of silt, sand, and gravel. The colluvium consists of gravelly clay averaging about 5 feet thick. Terrace deposits occur upstream and downstream, and cover part of the foundation in the channel. These consist of 5 to 20 feet of sandy clay overlying 3 to 15 feet of silty, clayey sand and gravel.

Small areas of older terrace deposits occur near the lower portions of the abutments.

Structure

Conglomerate, sandstone, and mudstone beds strike north-south and dip 50-80 degrees to the east.

There are five faults crossing the foundation area. They are roughly parallel, striking N50E across the regional bedding. Mapping and drilling show that the faults dip steeply and offset bedrock units. The faults range in width from a few feet to over 40 feet and typically consist of highly fractured rock with seams of gouge. Some faults have been partially cemented with calcium carbonate.

Two sets of joints are prevalent. One set strikes northeast and dips near vertical; the second set strikes parallel (north-south) to the ridge and dips east or west at zero to 45 degrees. Joint spacing is widest in the conglomerate beds (2 to 7 feet) and somewhat more closely spaced in the sandstone (less than 1 to more than 5 feet). Joints in the mudstone are generally closely spaced.

Exploration

USBR mapped the dam site, drilled and water pressure tested 10 core holes, and drilled 12 bucket auger holes near the dam site to investigate construction materials. DWR drilled and water pressure tested 11 core holes and excavated 10 trenches to explore the foundation. DWR also ran 18 geophysical survey lines to explore the subsurface.

Permeability

The foundation rocks are mostly low permeability, but faults, fractures, and joints contribute to local seepage. Water pressure testing of ten channel holes showed low water takes. Grout takes should be generally low, but higher locally where fractures are present.

Foundation Preparation

Clearing will be minimal at Newville Dam site. Scattered oaks and brush occur on both abutments. Some riparian growth occurs in the channel area.

Exploration drilling, trenching, and geologic mapping indicate that the rock on both abutments is intensely weathered to a depth of about 5 feet and fresh rock is found at about 15 feet. Soil depth is generally less than 3 feet. Alluvium depths in the channel average 5 feet and an additional 20 feet of weathered rock overlie fresh rock.

Average depths of stripping under the outer shells are estimated to be about 10 feet on the right abutment, 20 feet in the channel area, and 10 feet on the left abutment. Under the impervious core, the average stripping depth would be about 15 feet on the abutments and 40 feet in the channel. Additional excavation may be required in more weathered areas, along faults, and in lenses of poorly cemented conglomerate.

Construction Materials

Materials are available nearby for construction of the various features, but additional work is needed to evaluate alternative sources and their quantity and quality. Local sandstone and conglomerate appear to be weaker and less durable than the usual quarried rock for use in dams. The dam could be designed to accommodate this, but it would probably prove more economical to use stream gravel for transition zones and basalt for riprap. The stream gravel would probably come from upper Stony Creek and the basalt from the east side of the Sacramento Valley.

There are several adequate and tested sources of construction materials for an embankment-type Newville Dam. These are:

- Good quality impervious material for Newville Dam and Burrows Gap Saddle Dam is found within the reservoir area. About 90 percent of the needed pervious material can be found in Stony Creek between Julian Rocks and the Grindstone Indian Rancheria and in Grindstone Creek east of the Coast Range front. The environmental impact and acceptability of removing stream channel deposits should be evaluated. Dewatering will be required for some of the impervious deposits and all of the pervious.
- Tehama Formation deposits for the impervious core are located 5 miles east of the dam site.
- Terrace and slopewash deposits for the core and random fill portions of the embankment are located in the reservoir area and adjacent to the dam site.
- Stream gravel for filters and concrete structure is located within 7 to 12 miles of the dam site along Stony Creek between Black Butte Lake and Stony Gorge Dam. The use of stream gravel from streams with anadromous fisheries such as Thomes and lower Stony Creeks is not being considered at this time.
- Quarried sandstone and conglomerate from the Great Valley Sequence may be used for the rockfill and random zones of the embankment. The potential borrow sites nearest the dam site are of limited extent and contain large percentages of weathered rock. The most promising borrow area, with 21 million cubic yards of material, lies 3 miles north of the dam site. Preliminary laboratory tests show that the low strength and durability would require more conservative embankment slopes than are customary in high rockfill dams. The quarry source may also be used for riprap, but laboratory tests show that the rock is marginal for this use. Additional sources occur on the east side of the Sacramento Valley.

Several potential quarry sites have been identified and some drilling and laboratory testing have been completed on sandstone and conglomerate deposits from Rocky Ridge north of Newville Dam site. At the conclusion of the studies in 1982, a test fill was recommended to evaluate the conglomerate from Rocky Ridge as a rock source.

Burrows Gap Dam Site Geotechnical Studies and Findings

The Burrows Gap Saddle Dam would be an earth or rock embankment with an internal filter and drain. It would function as a saddle dam for reservoir levels above 780 feet. This saddle dam for the 1.9 maf Newville Reservoir would

be about 75 feet high and 450 feet long and would span a low saddle in Rocky Ridge 3 miles south of the Newville Dam site.

Bedrock

The rock units at Burrows Gap are part of the Stony Creek Formation. They are nearly identical to the conglomerate, sandstone, and mudstone units found at Newville. The main section of the dam would be founded on conglomerate and sandstone. The upstream section of the embankment would be founded partially on mudstone.

Structure

The conglomerate and sandstone beds strike north-south and dip about 60 degrees toward the east. Burrows Gap is a faulted saddle in Rocky Ridge. The northeast-trending fault zone that passes through the gap is considered to be inactive (ESA 1980). The fault appears to be 3 to 10 feet wide.

Exploration

The geology at the site was mapped by DWR in 1961 and by USBR in 1966 (DWR 1980). This mapping was field-checked and revised by DWR in 1982. One angled core hole, drilled to a depth of 275 feet, and two geophysical survey lines provide the only subsurface information at the site.

Foundation Preparation

Stripping the foundation will consist of removing soil and weather rock under the embankment area and excavating a key trench. Soil, colluvium, and intensely weathered rock should be about 5 feet deep on the left abutment. In the saddle and on the right abutment, it will average 10 to 12 feet.

The rocks that make up the foundation are essentially impervious below 50 feet. However, the east-west-trending joints and fractures related to the fault zone could contribute to seepage beneath the dam. There is a seep near the downstream embankment toe, which is probably related to the presence of the fault. Seepage should be controllable with a grout curtain under the foundation and a filter drain.

Construction Materials

The same sources of construction materials as the Newville Dam are available.

Red Bank Project

The geologic studies conducted at the dam sites and along the conveyance routes indicate that the foundations are suitable for the proposed structures. The dams would be constructed from roller-compacted concrete (RCC) using quarried and crushed sandstone. The Red Bank Project was initially envisioned as two large embankment structures—Dippingvat Dam on South Fork Cottonwood Creek and Schoenfield Dam on Red Bank Creek—but were switched to RCC structures. The geology of the Red Bank Project was

documented in the 1980 DWR report, "Engineering Geology of the Red Bank Project, Tehama County, California."

Reevaluation of the seismic conditions (Appendix O) has resulted in an increase of the Maximum Credible Earthquake that could occur for the project. The reevaluation could also impact the proposed design. William Lettis and Associates are presently conducting additional studies related to the seismic characteristics associated with the project.

Dippingvat Dam Site Geotechnical Studies and Findings

Dippingvat Dam site is located on South Fork Cottonwood Creek and would be an RCC structure.

Bedrock

The dam site lies within the Great Valley Sequence along the west boundary of the Sacramento Valley. The foundation bedrock consists mostly of Upper Cretaceous sandstone, with lesser amounts of interbedded mudstone and minor conglomerate, and with bedding thickness varying from less than 1 inch to tens of feet. The sandstone forms prominent ridges in the area.

The sandstone is medium green, hard, and well indurated. The mudstone is dark gray to gray, and generally finely laminated to thinly bedded. It is generally closely fractured and slakes where exposed to air and moisture. The conglomerate only occurs in one layer interbedded with the sandstone. It is also hard and well indurated.

Surficial Deposits

Colluvium and stream channel deposits are at the dam site. Terrace deposits occur 150 feet upstream of the proposed dam axis. The colluvium, stream channels, and terrace deposits cover bedrock locally up to 10 feet.

Structure

The conglomerate, sandstone, and mudstone beds trend northwest and dip about 60 degrees to the east.

Three faults are in the foundation. All were intersected during the drilling. Associated with the faults are zones of gouge and sheared bedrock from 2 to 10 feet wide. Trenching to determine recency of faulting has not been conducted.

Exploration

The geology was investigated by DWR between 1987 and 1990. Six diamond core holes were drilled and water pressure tested at the dam site. No additional geologic field work has been completed.

Permeability

A grout curtain to about 150 feet deep in the abutments and 70 feet under the channel should be sufficient to control foundation seepage. There is some concern that open joints and fractures in the right abutment conglomerates may require treatment. Grout takes are expected to be low, except for some zones with moderate to high takes.

Foundation Preparation

Foundation preparation should include the stripping of about 24 feet of colluvium, soil, and loose weathered bedrock from the left abutment, 13 feet from the right abutment, and several feet from the channel. Another 10 feet of fractured and moderately weathered bedrock may have to be removed. Some dental work along the fault crossing the axis may be required.

Construction Materials

Aggregate construction material for the RCC dam is available about one-half mile downstream. The sandstone is interbedded with some mudstone, which will be removed before crushing.

Schoenfield Dam Site Geotechnical Studies and Findings

The geology is similar to Dippingvat Dam site. The dam site would be founded on the Great Valley Sequence of mudstone, conglomerate, and sandstone.

Surficial Deposits

Patches of Quaternary stream alluvium cover the channel locally to depths up to 9 feet. Several levels of scattered terrace deposits occur upstream within 600 feet of the dam axis. The terraces consist of 1 to 3 feet of clayey silt overlying 3 to 5 feet of gravel and cobbles perched on a bedrock bench about 5 feet above the present channel level. Colluvium wedges occur at the base of the slopes in depths approaching 10 feet or more. The colluvium consists of a mixture of soil and angular rock fragments.

Structure

The major structural feature is the northwest-trending, homoclinally east-dipping bedding of the Cretaceous Great Valley Sequence. Bedding attitudes trend northwest and dip northeast about 45 degrees and joints are common.

There are two mapped faults and several shears that are present in the foundation. Both faults are roughly perpendicular to the regional strike of bedding. Trenching to determine recency of faulting has not been conducted.

Permeability

In general, the rocks in the foundation were hard, well indurated, and of sufficient strength for the proposed dam. Water pressure data showed that water takes were generally low to moderate, with some zones of higher takes. The rocks have little primary permeability. Instead, zones of high water take are associated with extensive fractures or jointing. The conglomerate has the highest take due to open fractures. The zones of fractured rock associated with faulting may act as seepage paths.

Foundation Preparation

Foundation preparation of the abutments will consist of the removal of brush interspersed with oak and pine. About 10 to 16 feet of soil, colluvium, and intensively weathered bedrock can be removed with common methods. An

additional 5 to 10 feet of moderately weathered bedrock may require some blasting. An average of about 5 feet of stream alluvium and up to about 10 feet of weathered bedrock needs to be removed from the channel. The two fault zones crossing the dam site may require some treatment. Grout take, based on water pressure testing, is expected to be moderate overall, but with zones of high grout take in places.

Construction Material

The construction material initially selected for RCC structures is from a sandstone quarry site located one-half mile downstream. The quarry consists of one sandstone bed about 100 feet thick and a number of thinner beds. Two diamond core holes were drilled and samples sent to the laboratory for analyses. In addition, a series of mixes of sandstone aggregate, cement, and pozzolan were tested for compressive strength. The testing showed that the sandstone aggregate was adequate for the previously-proposed, seismic loading criteria.

Bluedoor and Lanyan Dam Sites Geotechnical Studies and Findings

The geology, seismic considerations, construction materials, and foundation preparation for Bluedoor and Lanyan Dam sites are similar to Schoenfield Dam site. These two proposed RCC dams are small and less than 100 feet high. Four diamond core holes were drilled at Lanyan and five at Bluedoor. The drill holes intersected minor gouge and fractured rock at both dam sites. Each hole was then water pressure tested. Grout takes are expected to be low except for some zones of high grout takes.